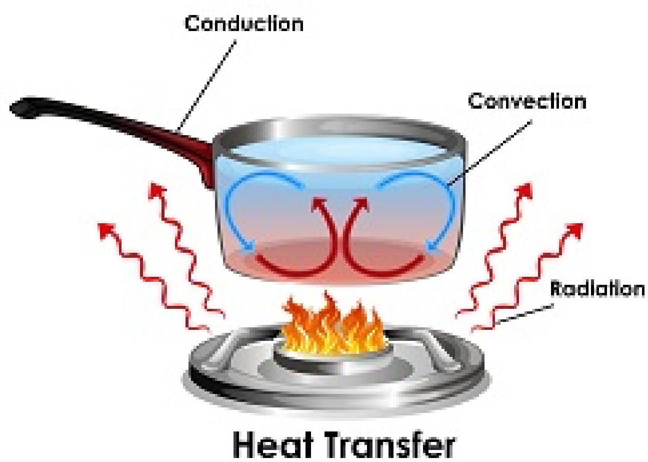
DEPARTMENT OF MECHANICAL ENGINEERING

ABIT

HEAT TRANSFER



MODULE-I

INTRODUCTION

INTRODUCTION

Heat

- Heat is a form of energy.
- It is the energy in transit.
- It is a boundary phenomenon.
- When two points in a medium are at different temperature, then the heat flows from a point at higher temperature to a point at lower temperature.

Sign convention

- Heat transfer to the system from the surroundings is taken to be positive and from the system to the surrounding is taken to be negative.

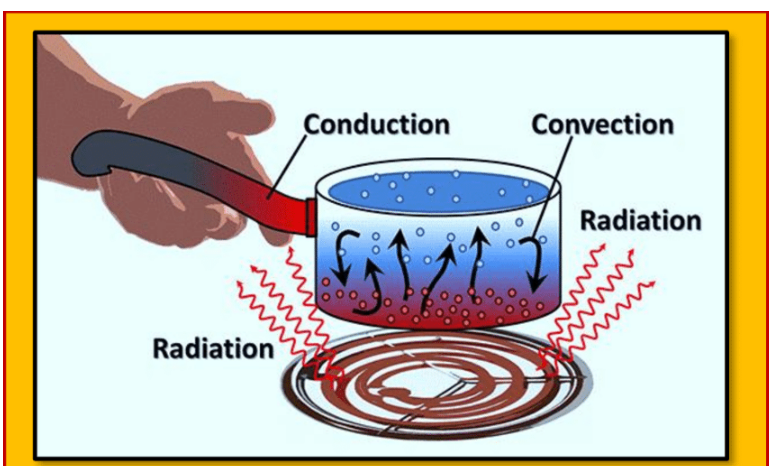
Applications

- Design of thermal power plants.
- Internal combustion engine.
- Refrigeration and air conditioning.
- Design of cooling systems for electric motors, generators and transformers.

Modes of heat transfer

There are three modes of heat transfer

(i) Conduction
(ii) Convection
(iii) Radiation



MODES OF HEAT TRANSFER-LINK BELOW

https://www.youtube.com/watch?v=FTSBtx5jhaY

https://www.youtube.com/watch?v=kNZi12OV9Xc

PPT

https://www.slideshare.net/hmsoh/coduction-convection-and-radiation?next_slideshow=1

https://www.slideshare.net/SurenderRawat3/heat-transfer-41318661#:~:text=Also%20called%20fourier's%20law%20%E2%80%A2,which%20the%20heat%20is%20flowing.&text=9.

Conduction

- It is a mechanism of heat propagation from a region of higher temperature to a region of lower temperature within a medium or between different mediums in direct physical contact.
- It does not involve any macroscopic movement of matters relative to one another.
- It is mainly due to random molecular motion and so it is called microform of heat transfer or diffusion of energy.
- Thermal energy may be transferred by means of electrons which are free to move through the lattice structure of the material.
- It may also transfer as vibrational energy in the lattice structure.
- It is a microscopic form of heat transfer.

CONDUCTION-LINK BELOW

https://www.youtube.com/watch?v=NKZSImhSn6k

Fourier's laws of heat conduction

Joseph Fourier-LINK- https://en.wikipedia.org/wiki/Joseph_Fourier

It may be stated as follows:

- "The rate of flow of heat through a solid is directly proportional to the area of the section at right angles to the direction of heat flow, and to change of temperature with respect to the length of the path of the heat flow."
- Mathematically, it can be written as

$$Q \alpha A.\frac{dt}{dx}$$

Where , Q= Heat flow through a body per unit time (in watts) W,

A = Surface area of heat flow (perpendicular to the direction of flow),m^2

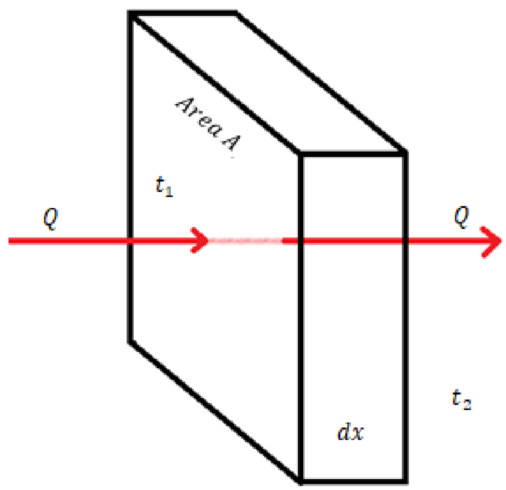
dt = Temperature difference of the faces of the solid of thickness 'dx' through which heat flows, ^{0}C or K,

dx = Thickness of body in the direction of flow, m.

Thus,
$$Q = -K.A.\frac{dt}{dx}$$

Where, K = Constant of proportionality and is known as thermal conductivity of the body.

- The –ve sign is to take care of the decreasing temperature along with the direction of increasing thickness or the direction of heat flow.
- The temperature gradient dt/dx is always negative along positive x direction and, therefore , the value as Q becomes + ve.



Assumptions

The following are the assumptions on which Fourier's law is based

(i) Conduction of heat takes place under steady state conditions.
(ii) The heat flow is unidirectional.
(iii) The temperature gradient is constant and the temperature profile is linear.
(iv) There is no internal heat generation.
(v) The material is homogeneous and isotropic (i.e., the value of thermal conductivity is constant in all directions).

Thermal conductivity of materials

We know from Fourier equation,

$$Q = -K.A.\frac{dt}{dx}$$

The value of K=Q, when A=1 and dt/dx=1

Thus , thermal conductivity of a material is defined as follows:

"The amount of energy conducted through a body of unit area , and unit thickness in unit time when the difference in temperature between the faces causing heat flow is unit temperature difference.'

Unit of thermal conductivity

$$K = \frac{Q}{A}.\frac{dx}{dt} = \frac{W}{m^2}\frac{m}{K or ^0C} = W/mK or W/m^0C$$

Thermal conductivity of some common materials

Material	Thermal conductivity(K) (W/Mk)	Material	Thermal conductivity(K) (W/Mk)
1. silver	410	8. asbestos sheet	0.17
2. copper	385	9. ash	0.12
3. aluminium	225	10. cork	0.05-0.10
4. cast iron	55-65	11. saw dust	0.07
5. steel	20-45	12. glass wool	0.03
6. concrete	1.20	13. water	0.55-0.7
7. glass (window)	0.75	14. Freon	0.0083

Wiedemann and Franz law (regarding thermal and electrical conductivities)

It is stated as follows,
" The ratio of the thermal and electrical conductivities is the same for all metals at the same temperature and that the ratio is directly proportional to the absolute temperature of the metal."

Mathematically, $\frac{K}{\sigma} \alpha T$

Or, $\frac{K}{\sigma T} = C$

Where, K= Thermal conductivity of metal at temperature T(K),
σ= Electrical conductivity of metal at temperature T(K).and
C= Constant (for all metals) referred to as Lorenz number($=2.45 \times 10^{-8} W\Omega/K^2$, Ώ stands for ohms)

This law conveys that the materials which are good conductors of electricity are also good conductors of heat.

Electrical analogy

- When two systems are described by similar equationsand have similarboundary conditions , these are said to be analogous.The heat transfer process may be compared by analogy with the flow of electricity in an electrical resistance.
- As the flow of electrical current in the electrical resistance is directly proportional to potential difference (dV), similarly heat flow rate , Q , is directly proportional to temperature difference(dt) , the driving force for heat conduction through a medium.
- As per Ohm's law, we have,

$$\text{Current(I)}=\frac{Potentialdifference(dV)}{Electricalresis\tan ce(R)} \qquad \text{(i)}$$

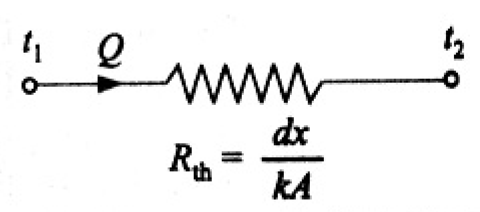
By analogy , the heat flow or Fourier's equation may be written as

$$\text{Heat flow rate(Q)}=\frac{Temperaturedifference(dt)}{\frac{dx}{KA}} \qquad \text{(ii)}$$

By comparing both equations (i) and (ii) , we find that I is analogous to , Q, dV is analogous to dt and R is analogous to the quantity (dx/KA). The quantity dx/KA is known as thermal resistance,i.e.

$$(R)_{th}=\frac{dx}{KA}$$

- The reciprocal of the thermal resistance is called thermal conductance.



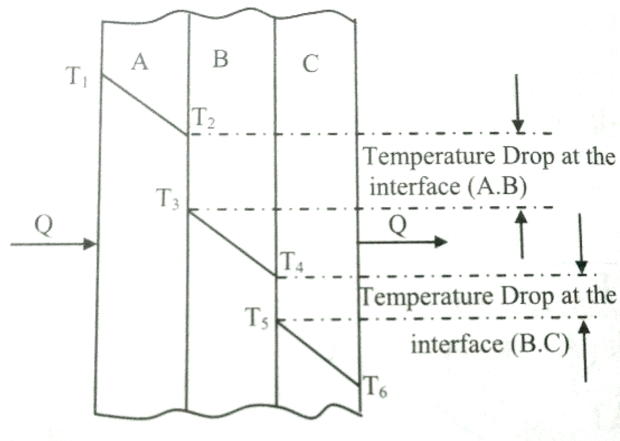
Contact resistance

Heat flow through multi-layer composite wall can be calculated based on the following assumptions

- There is perfect contact between adjacent layers
- The temperature is continuous at the interface
- There is no fall of temperature at the interface

But, practically the contact surfaces touch only at a discrete locations due to surface roughness and the void spaces are usually filled with air. There is no single plane of contact. This means that the area for heat flow at the

interface will be small compared to the geometrical area of the face. Due to this decrease in the heat flow area and also due to the presence of voids , there occurs a large resistance to heat flow. This resistance is referred as thermal contact resistance and it causes temperature drop between two materials at the interface.



The contact resistances are given by

$$(R_{th\text{-}AB})_{contact} = \frac{(T_2 - T_3)}{Q/A}$$

$$(R_{th\text{-}BC})_{contact} = \frac{(T_4 - T_5)}{Q/A}$$

SOLVED PROBLEM WITH CONTACT RESISTANCE-LINK BELOW

https://www.youtube.com/watch?v=rArjlreclXc

Convection

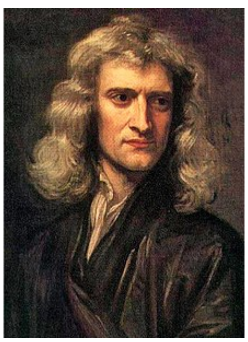
Convection is the mode of heat transfer between a surface and a fluid moving over it.

- The energy transfer in convection is mainly due to bulk motion of fluid particles.
- If this motion is mainly due to density variations then it is called free or natural convection.
- If this motion is produced by some superimposed velocity field then it is called forced convection.

Convection-LINK BELOW

https://www.youtube.com/watch?v=VxGIiOTuAIs

Newton's law of cooling



Sir Isaac Newton-LINK- https://en.wikipedia.org/wiki/Isaac_Newton

- The rate equation for the convective heat transfer between a surface and an adjacent fluid is given by Newton's law of cooling.

$$Q=hA(t_s-t_f)$$

Where Q= rate of heat transfer,
A= area exposed to heat transfer,
t_s = surface temperature
t_f = fluid temperature, and
h=co-efficient of convective heat transfer

The units of h are,

$$h=\frac{Q}{A(t_s-t_f)} = W/m^2C \text{ OR } W/m^2K$$

The coefficient of convective heat transfer 'h' is defined as
"the amount of heat transferred for a unit temperature difference between the fluid and unit area of surface in unit time."
The term 1/hA is called convective thermal resistance

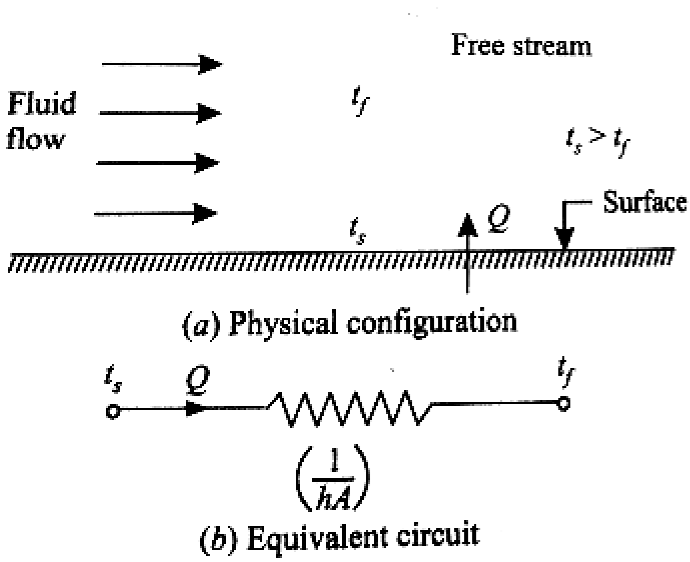


Fig. Convective heat-transfer

Radiation

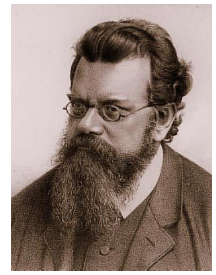
- It is the transmission of heat in the form of radiant energy or wave motion from one body to another across an intervening space.
- An intervening medium is not even necessary and the radiation can be affected through vacuum also and more effective is in vacuum only.
- Mechanism of radiation is divided into 3phases
  - Conversion of thermal energy of the hot source into electromagnetic waves.
  - Passage of wave motion through intervening medium.
  - Transformation of waves into heat.
  - Thermal radiation is limited to wavelengths ranging from 0.01 to 100µm of the electromagnetic spectrum.
  - Examples: Boiler furnace, solar radiation, earth radiation, due to high temperature surfaces.

RADIATION-LINK BELOW

https://www.youtube.com/watch?v=tZliZyoYT80

Stefan-Boltzmann law

Josef Stefan



Ludwig Boltzmann

LINK- https://en.wikipedia.org/wiki/Josef_Stefan https://en.wikipedia.org/wiki/Ludwig_Boltzmann

- The law states that the emissive power of a black body is directly proportional to fourth power of its absolute temperature.

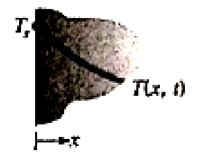
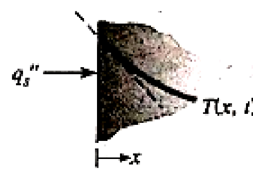
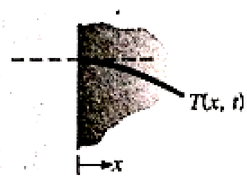
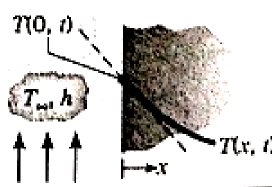
  i.e. $Q \propto T^4$

  or $Q = \sigma A T^4$

  where σ = Stefan-Boltzmann constant= $5.67 \times 10^{-8} W/m^2K^4$

Initial conditions and Boundary conditions of 1st, 2nd and 3rd Kind.

TABLE Boundary conditions for the heat diffusion equation at the surface ($x = 0$)

1. Constant surface temperature $T(0, t) = T_s$	
2. Constant surface heat flux (a) Finite heat flux $-k \frac{\partial T}{\partial x}\Big\vert_{x=0} = q_s''$	
(b) Adiabatic or insulated surface $\frac{\partial T}{\partial x}\Big\vert_{x=0} = 0$	
3. Convection surface condition $-k \frac{\partial T}{\partial x}\Big\vert_{x=0} = h[T_\infty - T(0, t)]$	

BOUNDARY CONDITIONS – LINK BELOW

https://www.youtube.com/watch?v=_F09zV0n22o

REFERENCES

1. Heat and Mass transfer, author-R.K.RAJPUT
2. HEAT AND MASS TRANSFER, AUTHOR-FRANK P. INCROPERA , DAVID P. DEWITT
3. GATE STUDY MATERIAL, ACE ENGINEERING ACADEMY
4. GOOGLE IMAGE
5. YOUTUBE